SUMMARY OF GLACIAL LITERATURE RELATING TO GLACIAL DEPOSITS.

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GLACIAL DRIFT.

DEFINITION.—"Glacial drift is an accumulation of earthy materials—clay, sand, gravel, and boulders—which has been transported by moving masses of ice and deposited over portions of the earth's surface, mostly in the higher latitudes."—*Standard Dictionary.*

"This aggregation of surface material which overlies different formations indiscriminately, and which is composed of materials which could not have been derived wholly from the underlying rock, is called drift."—*Rollen B. Salisbury.*

GENETIC CLASSIFICATION.

BASED upon the origin of their formation, glacial deposits are classed as subglacial, englacial, superglacial, and extraglacial.

SUBGLACIAL DEPOSITS.

The subglacial deposits are those deposits which are dragged along beneath the ice or are formed beneath the ice. They are: Lower till, ground-moraine, or boulder-clay. This is the "hard-pan" clay formation found throughout glaciated regions. It is sometimes called boulder-clay because it contains boulders and pebbles. It is the product of abrasion caused by the stones held in the moving ice-sheet grinding the bed-rock into powder, and the bed-rock, in turn, reducing them to the same material. When the great ice-sheet melted its load was dropped, and in this deposit the coarser and finer materials beneath the sheet were indiscriminately mixed; thus the till or rock-flour.

An examination of this till in Wisconsin gave the following results: It is of medium hardness when dry and slakes readily in water, breaking down into a finely pulverulent mass which has a fair degree of hardness. Under the microscope the grains were observed to have diameters ranging from 10 mm. to 0.003 mm. A very small percentage of the individuals are less than 0.0058 mm. in diameter. The larger grains are fairly well rounded, but the smaller ones have angular outlines.

To use the Standard Dictionary definition for this formation, it is "an accumulation of earthy materials—clay, sand,

gravel, and boulders—which has been deposited over portions of the earth's surface, mostly in the higher latitudes."

GUMBO.—This formation is the stratified portion of the lower till of the Mississippi valley. It is a granular, adhesive clay, often several feet in thickness. It is not such a continuous deposit as the overlying loess, there being many places where the loess rests directly upon typical till. Like the loess, though, it seems to be independent of contour lines in its distribution. Its color varies from light gray or ash to nearly black. The black portions are heavily charged with humus and in places present the appearance of swamp muck. It is from this clay that the black soil so often seen at the base of the loess is usually developed. This gumbo clay contains a few pebbles, much less than the typical till or loess. According to Mr. Leverett, these deposits may be of aqueous origin; but such an hypothesis cannot be confidently put forward as a solution.

DRUMLINS.—A drumlin is a smoothly rounded hill. Mounds or hills of this sort are found all over the glaciated region, from Maine to the Rocky Mountains. Their origin is in doubt. Prof. G. F. Wright[1] and others believe that during the final melting of the ice the surface would melt unequally, since the large boulders and deeper masses of till would partially protect the ice beneath them from melting, and that, consequently, there would be much lateral sliding of till into the depressions thus formed on the ice surface, which, when the glaciers disappeared, would remain as drumlins. But it is difficult to conceive how smoothly rounded hills in such large numbers and such great size could result from this process. Moreover, some of the masses of thoroughly glaciated matter are long ridges parallel with the glaciation, masses still more difficult of explanation as being due to accumulation in surface hollows of the ice.

Prof. N. S. Shaler[2] believes that these hills are the remains of a former sheet of till of which the greater part has been eroded by the sea waves, but to this opinion there are many objections: First, these deep masses of till are sometimes one mile or more from any similar mass. The amount of erosion required is enormous. Second, had a great mass of till been eroded, most of the larger stones would now remain as broad

1. Wright, Ice Age of North America.
2. Bull. Geol. Soc. Am., vol. 10; also Shaler and Davis, Glaciers.

sheets in the valleys or as terraces on the hillsides, a phenomenon which does not exist. Third, had the till been eroded in the manner supposed above, the erosion must have occurred before the deposition of the marine beds; and these beds, in turn, would preserve the beach gravels beneath them from erosion. No such rolled gravels now exist beneath the clays. Fourth, had there been such an erosion of the till, the kames and marine deltas would not have escaped in such a good state of preservation. Fifth, the lenticular sheets of till on the northern slopes of hills must have substantially the same origin as drumlins themselves. Yet there are multitudes of these hillside lenses in regions where no genuine water-washed gravel is to be found.

Another theory is that drumlins are the remains of a former sheet of till irregularly eroded by the glacier. But it is difficult to see how a glacier can deposit till and not at the same time deposit glacial gravel.

In speaking of the drumlins of New Hampshire, Emerson says:[3] "Could one raise the stratum of stony clay which overspreads the valleys, as one lifts a plaster mask from the face, it would be found that its under surface had been exactly molded to every line and curve in the rocky substratum; but its upper surface would have the effect of a comic mask, swelling with unequal thickness over every prominent feature, distorting and concealing its true form, and sending up great protuberances due wholly to a thickening of its own mass and not molded on any projecting ledge below. The protuberances formed thus by local thickening of the sheet appear now as drumlins, massive domed hills, in shape like an inverted canoe, with their long axes pointing in the direction of glacial motion from north to south."

Hitchcock and Wright have thought drumlins to be, perhaps, the material of terminal moraines swept over and massed in these peculiar forms by subsequent farther advances of the ice-sheet.

King and Dana have conjectured that drumlins, at least in some cases, were made by superglacial streams, charged with drift, pouring through crevasses or a moulin to the land surface, there depositing their drift, which afterwards by the outflow of the ice would be subjected to its pressure and sculpturing.

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3. Monograph 29, p. 545.

Geike, Davis and Salisbury look on drumlins as analogous to the sand-bars of streams.

In speaking of the origin of drumlins, Upham in substance writes:[4] "The till forming drumlins invariably exhibits the characteristic features of subglacial drift or ground-moraine, excepting its superficial portion which was englacial and subglacial when the ice-sheet melted away."

His hypothesis of the drumlin accumulation is somewhat as follows: "In the central area of the ice-sheet the currents of its upper and lower parts probably moved outward with nearly equal rates, the upper movement being slightly faster than at the base. Upon a belt extending many miles back from the margin, however, where the slope of the ice surface had more descent, the upper currents of the ice, unsupported on the outer side, would move faster than its lower currents, which were impeded by friction on land. There would be accordingly in this belt a strong tendency of the ice to flow outward with somewhat curved currents, tending, first, to carry the onwardly moving drift gradually upward into the ice-sheet, and, later, to bear it downward and deposit it partly beneath the edge of the ice and partly along the ice boundary. And as the ice at the time of its melting was making halts and occasionally readvancing, if the ice had nearly a constant position during several years, its border became marked by terminal moraines close to the glacial boundary. Whether it halted and ever readvanced, or merely its retreat was much slackened, the upper part of the ice must have descended over the lower part. This differential and shearing movement gathered the stratum of englacial drift into the great lenticular masses or sometimes longer ridges of the drumlins, thinly underlain by ice and overridden by the upper ice flowing downward to the boundary and bringing with it the formerly higher part of the drift stratum to be added to these ground-drift accumulations. The courses of the glacial currents and their convergencies to the places unoccupied by drumlins were apparently not determined so much by the topography of the underlying land as by the contour of the ice surface, which, under its ablation, had become sculptured into valleys, hills, ridges, and peaks, the isolation of the elevations by deep intervening hollows being doubtless most conspicuous near the ice margin. And again, when the boundary

4. See Upham, Glacial Lake, Agassiz, G. S. Monograph xxv, and Ice-sheet Moraine, Geol. Surv. Minn., 1880.

receded the upper currents of the outer belt of the ice, upon a width of probably ten miles, would pour down toward the open land, causing the deposition of much subglacial till; and whenever a stratum of the englacial drift became covered with new ice, it would probably be aggregated englacially or altogether subglacially in drumlins.

"And to conclude, drumlins are the effects of secular vicissitudes of climate on the border of the departing ice-sheet, which seems to have owed its existence to the great altitude of the land at the beginning of the glacial period. This glacier seems to have been atended, when at its maximum extension and volume, by depression of the land on which it lay, and to have witnessed, during the retreat and removal of its load, a progressive reelevation of the same area to its present height."

Remarks on Drumlins.—Drumlins could not have been formed by the tidal or river erosion of a once continuous sheet of drift nor to the excavation and removal of the drift from all intervening areas by the later glaciation mentioned, because, to accord with this view, the terminal moraine of the later ice-sheet must vastly exceed their moderately observed volume. (2) They are not the material of terminal moraines swept over and massed in these peculiar forms by subsequent farther advances of the ice-sheet, because neither the distribution nor the composition of drumlins seems to favor such an hypothesis. (3) They were not made by superglacial streams, charged with drift, pouring through crevasses or a moulin to the land surface, there depositing their drift; because there are no signs of stratification, and because the distribution and composition oppose such a theory. (4) Drumlins are not analogous to the sand-bars of streams, because the areas bearing them are not determined chiefly by the topography and rock structure. (5) They do not seem to have been formed by subglacial drift, leached out from the melting ice by surface-melting and gathered from a large area of the ice surface and concentrated on a smaller one by water action, thus to be transformed into drumlins of true till, for the following reasons: (*a*) The whole mass of the accumulated concentrated surface drift must have been worked over bit by bit by the ice before it could gain the structure of till. This would seem to be a useless concentration, except as affording a possible excessive supply of ready material for ice-dragging. (*b*) The theory as a whole seems to be founded upon special interpre-

tations of phenomena that are difficult to explain. (*c*) The excess of subglacial drift in drumlins opposes the interglacial theory of their accumulation.

The drumlin investigations and arguments given above seem to show that drumlins were formed on the protected side of some projecting hard substance which resisted the wear and erosion of the ice. They seem to have collected in a way similar to the way snow drifts behind a wind obstruction, except that it was closed in at the top and on the sides by ice. Drumlins being more numerous in mountain regions where there would be immovable obstacles to the ice advance, over which the ice must pass, seem to bear out this conclusion. A drumlin may therefore be defined as a lenticular, compact, unstratified mound or hill having its longer axis parallel with the direction of local glacial striation.

DRUMLIN VARIETIES.—Mr. Chamberlin recognizes four subvarieties of drumlins, as follows:

Lenticular or Elliptical Hills.—These consist of very remarkable aggregations of till in hills of dolphin-back form whose longer axes are two or three, or at most a few times longer than their transverse diameters. Their longer axes lie in the direction of the glacial movement.

Elongated Ridges.—These have the same constitution as the preceding and have similar terminal contours. They differ from the above principally in the fact that they are elongated more, their length often exceeding three miles.

Mammilary Hills.—These have the same constitution as the previous types, but differ from them in the extreme shortness of the axis, the axis often being scarcely longer than the transverse diameter. Though nearly round in form they are always elongated in the direction of glacial movement.

Till Tumuli.—These are low mounds of more than usually stony material, as a rule. They have not generally assumed the drumloidal curves of contour and profile, but their nature is such as to have suggested that they are the immature nuclei of drumlins. Their genesis, however, is in doubt.

DEPOSITS THAT ARE SOMEWHAT DRUMLOIDAL IN FORM.

CRAG AND TAIL.—These embrace the well-known accumulations of till in the lee of rocky crags or embossments.

PRE-CRAG.—These embrace the less well-recognized accumulations of till in the lee of rocky crags.

VENEERED HILLS.—These are hills of rock coated somewhat uniformly with till, the surface conforming approximately to that of the underlying rock. These differ from the last two formations mentioned in that they have a much more uniform distribution over the rock embossments and in the subordination of veneering of the preexistent contour rather than the formation of a new contour.

TILL BILLOWS.—These differ from true drumlins in their want of conformity to axes lying in the direction of the drift movement; and in that they are arranged more closely together, are disposed more irregularly, and are connected with each other by saddles or cols. The type graduates into submarginal moraines. They seem to be intermediate between submarginal moraines and drumlins.

IRREGULAR TILL HILLS.—These hills are aggregations of till that seem to pay no respect to laws of symmetry or systematic principles of growth. Their genesis is wholly in doubt.

SUBGLACIAL STREAMS.

These are streams that run beneath the ice-sheet. Their action is not unlike that of any other stream, except that it may be occasionally dammed with ice or may not keep the center of the valley, as non-glacial streams do. They are crowded from the center by the ice or even compelled to cross the valley from side to side time after time.

DEPOSITS OF SUBGLACIAL STREAMS.

OSARS.—An osar is a long, continuous, serpentine ridge of glacial sand or gravel, sometimes carrying boulders superficially, extending down valleys in the direction of glacial movement. Ridges of this sort are sometimes called serpentine kames. The following are some of the varieties:

SHORT ISOLATED OSARS OR ESKARS.—Ridges of this type are the simplest form of glacial gravel. They have here been called "isolated" because no other glacial gravels are known to be near them. They have the form of a cone, a dome, or often a short ridge, or sometimes several short ridges having a linear arrangement (lengthwise of the ridges), or occasionally a few somewhat parallel ridges inclosing basins. They vary in length from a few feet up to a mile or two. A distinguishing feature of the class is that they have no fan-shaped or elongated delta showing assortment of gravel. From the observations it would seem that these osars were

formed in one of the following ways: (*a*) A sediment-laden superficial stream may have plunged down a crevasse and deposited the coarser sediment in a cave or pool within the ice that naturally formed near the base of the waterfall. (*b*) They may have collected in an enlargement of pool in the bottom of a channel of a superficial stream, or in a pot-hole or pool in the ice where the tributary streams joined the main channel. (*c*) They may have been formed in the tunnel of a subglacial stream.

HILLSIDE OSARS OR ESKARS.—These ridges are usually not very high—five to twenty feet—and vary in length from fifty feet to one mile. Their direction of extent is nearly the same as that of the ice flow, and, also, must be about the same as the direction of the slope of the ice surface in late glacial times. The sediments composing them are usually gravel and sand; but in some cases there are cobblestones, boulderites, and even a few boulders, all distinctly but not very much water-worn.

ISOLATED KAMES OR SHORT ESKARS (OSARS) ENDING IN A MARINE DELTA.—The word "isolated" is here used because no other gravels can be proved to have been deposited by the same glacial streams to which these are due. The field evidence indicates that they were deposited by subglacial streams. The ridges and small hills of these deposits converge into a small plain of horizontally stratified matter, showing clearly a horizontal transition of gravel into sand at the south. They are, in fact, hillside kames.

ISOLATED OSAR-MOUNDS OR MASSIVES NOT ENDING IN A MORAINE DELTA PROPER.—These deposits are mesas rather than ridges. They belong to the region below former sea-level. They are rather level on top, somewhat uneven of surface, but with no reticulated ridges or kettle-holes proper. The smoothness of the surface is, probably, due to wave action. These table-lands consist of sand, gravel and cobblestones mixed in alternating layers, but with no variation in texture from north to south. They were probably laid down in a pool where a superficial stream fell down a crevasse, or where a subglacial stream entered a pool or lake within the ice.

SYSTEMS OF DISCONTINUOUS OSARS.—In this class a number of short ridges, often fan-like, have been placed. They have

a linear arangement and other relations such that they are regarded as having been deposited by the same glacial river. These systems have nearly the same general directions as the continuous osars. Their topographical relations are, also, substantially the same, except that the gravel deposits of which the system is composed are from a few feet up to a mile or more in length and are separated by intervals varying within the same limits.

GLACIAL GRAVELS OF THE COASTAL REGION.—The glacial gravels of this type are found in three relations to marine clays: (*a*) The gravels have the same level as the clays and pass by degrees directly into them. This is the characteristic relation of the glacial deltas and marks the coarser glacial sediments as being laid down simultaneously with the clays. (*b*) The clays overlie the glacial gravels, either wholly covering them or covering their base. The gravels were first deposited within ice-walls, and subsequently, after the ice melted, the clays were deposited. (*c*) The sand and gravel of the upper parts of the osar gravels overlie the fossiliferous clays which cover the base of the same kames or osars. These can be accounted for in two ways: (1) The ridges were first deposited within the ice-walls; subsequently the ice melted and sea-water covered them. Moraine clay, or in some cases kame or osar boulder-clay, was laid down. (2) The sand and gravel which overlie the clay on the flanks of the osars may have been brought there by glacial streams.

SIMPLE TRACKS OR PATCHES OF DRIFT FORMED BY SUBGLACIAL DRAINAGE.—Thin sheets and lenses of gravel and sand in the midst of subglacial till are common phenomena in glacial regions; and, while in many cases they may have been produced by streams running in tunnels which afterwards shifted their position and left no other mark than these patchy deposits, it seems that many of these drift patches were produced by a diffuse and local drainage developed by one of several combinations of conditions while the ice was still present and continuing its deposit of till.

SUBMARGINAL DEPOSITS.—Submarginal ridges of till parallel with the ice border are often in evidence. These lie along what was the immediate border of the ice at certain stages of its retreat. They are thought to have been formed under the edge of the ice, but it remains to be determined to what extent they were accumulated under the immediate border of

the ice and to what extent they were deposited at the distance of one, two or three miles from the precise edge of the glacier. These ridges are from one to a few miles wide, are composed essentially of till, and possess, in the main, a gently flowing contour which distinguishes them from the rougher ridgings and sharper contours of frontal moraines.

LODGE MORAINES.—These moraines are found just under the thin border of the ice-sheet; and constitute a submarginal accumulation.

ENGLACIAL DRIFT.

This drift was borne within the ice-sheet itself, but at the melting of the ice it was so mixed with the superglacial material that it is difficult to separate the two.

ENGLACIAL STREAMS.

An englacial stream is a stream which flows within the glacier itself, a stream inclosed within the ice. The work that they may have performed in glacial times is as follows: (*a*) They may have amassed glacial sediment directly from the ice by melting the ice around the debris and transporting it. (*b*) They were often conduits for streams, otherwise subglacial, their mission being simply to protect the ground-moraine from erosion. Moreover, in them glacial gravels may have been deposited, in which case the stratification of the sediments was generally obliterated by the melting of the subadjacent ice.

SUPERGLACIAL DRIFT.

This drift was borne on the ice or at its margin. It was collected from the cliffs and towering peaks in the vicinity of the ice-sheet or was carried into it by superglacial streams. It may be classified as follows:

DUMP-MORAINES.—These are a variety of terminal moraines. They are formed from material borne on the ice-sheet (or within it) which is dropped at the terminus of the ice. This, when the ice remains stationary for a sufficient period, grows into a bordering ridge.

PUSH-MORAINES.—These are formed by the mechanical thrust of the ice when it advances against any incoherent material that lies in its path.

UPPER TILL.—This till is formed both by englacial and superglacial action. It is material let down over the whole territory of the ice-field, either during its successive stages of retreat or by being let down directly through the melting

of the ice when the glacier becomes stagnant. It forms a superglacial sheet quite analogous to the lower till already described. How much of it is englacial and how much is superglacial is still in doubt, but that it was formed both by englacial and superglacial agencies there is an abundance of evidence.

MEDIAL MORAINES.—These merge into dump-moraines at the frontal edge of the ice, and into upper till in cases in which they are let directly down by melting without being carried on to the terminus of the glacier. They are very subordinate elements in the great Pleistocene glacial deposits.

LATERAL MORAINES.—Moraines of this type formed along the sides of the glaciers. They are composed of sands, gravels and boulders, the boulders being the prominent constituent, whence the name "boulder train" which is often applied to this moraine. They are formed by the edges of the ice-sheet rubbing along the sides of the valley through which it travels, forming lateral embankments.

MEDIAL LATERAL MORAINES.—These are moraines formed by the junction and coalescence of two glaciers.

INTERMEDIATE OR INTERLOBATE MORAINES.—These are formed by the front action of two glacial lobes pushing their marginal moraines together and producing a common moraine along their line of contact. They are terminal moraines in character, but intermediate, or interlobate in position.

TERMINAL MORAINES.—Any special aggregation of drift along the margin of a glacier is a terminal moraine.

PERIPHERAL MORAINES.—A peripheral moraine is a moraine of the terminal type which marks only a temporary halt or insignificant advance of the ice-sheet.

Remarks on Morainic Structure and Material.—Considered in respect to its internal constitution, the morainic formation is distinguishable into several distinct portions: The one, usually the uppermost but not occupying the heights of the range where it has its best development, consists almost wholly of assorted and stratified material. The other element of this formation, and the one which constitutes its basal portion and its great core when developed under favorable conditions, consists of a confused commingling of clay, sand, gravel and boulders of the most pronounced type. There is every gradation of material, from boulders of many tons

weight down to the finest rock-flour. The corrosion of these boulders is of the glacial type, and examples presenting polished and striated faces abound.

SUPERGLACIAL STREAMS.—These are streams that run over the top of the glacier. They are of importance, because they may carry large amounts of sediment onto the glacier and deposit it.

DEPOSITS OF SUPERGLACIAL STREAMS.

MARGINAL DEPOSITS.—Under this class are embraced all the deposits of glacial streams that were made at the margin of the "mer de glace," and whose forms were dependent upon conditions that obtained at the margin of the ice-field.

SUPERGLACIAL OSARS (ASARS) OR ESKARS (KAMES OF SOME AUTHORS).—These are channel deposits which have retained their original elongated form and become ridges, and hence fall under the Scandinavian type. They were left (dropped) at the melting of the ice.

SUPERGLACIAL KAMES.—These were sheets or pockets of assorted material gathered on the surface of the ice and doubtless subjected to much disturbance and rearrangement in the process of descent at the melting of the ice-sheet. They now constitute undulatory tracts of drift or groups of hillocks scattered here and there over the glaciated region.

KAMES.—Kames are conical hills of discordantly stratified sand and gravel, formed as such by glacial deposition, generally in a system transverse to the glacial movement. They occur chiefly as components of terminal moraines. To use the words of Geikie, "seen from a dominant point . . . an assemblage of kames . . . looks like a tumbled sea." They are irregular heapings of assorted material, found along the border tracts, and also distributed over the entire area abandoned by the ice. They appear to be the products of relatively active, vigorous glaciers. They resemble osars in many respects, but differ from them in that they are transverse to the glacial movement.

OSAR (ESKAR) DELTAS OR FANS.—When the glacial streams reached the border of the ice-sheet and were free from bounding ice-walls, they spread themselves out widely and dropped a large portion of their load in the form of deltas or fans, hence the name overwash aprons.

OVERWASH APRON DEPOSITS.—Glacial overwash is the de-

posits laid down by glacial streams in the open valley just beyond the ice front. These sediments spread out and filled the valleys not unlike the sediments of Alpine glaciers do today. They left a rolling, uneven surface, with shallow hollows, but no deep kettle-holes or conspicuous reticulations. They are often distributed along the moraines for a great distance and constitute a fringe of assorted material to which Shaler has given the apt name "apron." The material varies widely in coarseness, according to the condition of the formation. Classified structurally, they are known as gravel, sand, and silt aprons.

OUTWASH APRON DEPOSITS.—These are tracts of assorted material formed by waters outflowing from the ice where no definite terminal ridging took place. This class is usually made up of sand.

PITTED PLAINS.

Both the osar deltas and the overwash aprons are characterized in certain regions by a surface marked with numerous depressions, sometimes symmetrical (kettles), sometimes irregular, with undulating bottoms and embracing knolls and subbasins, which give the surface an expression resembling kames. A part of these pitted plains seem to be intimately connected in origin with the ice edge and to be due to marginal conditions, of which it has been thought that the incorporation of ice fragments, the grounding of ice blocks, the movement of the ice edge, and the development of underground icesheets were among the special agencies.

OSAR PIT.—Another class of pits was found at the terminus of osars. They are probably due to the water's scooping out a hole at the point where the osar waters emerged from the ice. In many cases these holes are now swamps.

EXTRAGLACIAL DEPOSITS.

These deposits are of glacial origin. They, however, were laid down either by wind or water beyond the ice-foot. They are:

GLACIAL RIVER DEPOSITS.—These were laid down by the ice-streams as they issued from the body of the active glacier.

VALLEY DRIFT.—As the glacial streams were greatly overloaded with debris at their outlet they built up their valley bottoms by depositing material from bluff to bluff, forming a valley plain. Out of this, beautiful systems of terraces were

often cut. The most notable class of this type head in terminal moraines. Hence this drift affords valuable criteria for determining the altitude at the time of the formation.

Other classes of valley drift are the outwash and overwash apron deposits already described. Loess is also classed under this heading by a majority of the writers on the subject.

LOESS.—To quote Geikie: "This name was given to the deposit in Germany, where the deposit was first studied. It is usually a yellowish, homogeneous clay or loam, unstratified, and presenting a singular uniformity of composition and structure. When carefully examined, its quartz-grains are found to be remarkably angular, and its mica plates, instead of being deposited horizontally, as they are by water, occur depressedly in every possible position and with no definite order. The chief constituent of loess is always hydrate silicate of alumina, in which the scattered grains of quartz and flakes of mica are distributed. . . . Here and there the lime is segregated into concretionary forms by the action of infiltrating water. Though a firm, unstratified mass, it is traversed by innumerable tubes, formed by the descent of rootlets, and mostly incrusted with carbonate of lime. These have generally a vertical position and ramify downwards. These pipe-like lime concretions have a tendency to give a vertical jointing to the mass. The loess contains organic remains, chiefly land shells, sometimes in immense numbers, also bones of various herbiverous and carniverous animals, which are either identical with or closely related to species that abound on steppes and grassy plains to-day. Fresh-water shells are usually rare, and marine forms do not occur. Loess is found at elevations ranging from 5000 to 8000 feet above the sea in China, in which country it ranges in thickness from 500 to 2000 feet. It also occurs in most of the glacial regions of the earth. Various theories have been proposed in explanation of this singular deposit. By some it has been referred to the operation of the sea; by others to the work of lakes and rivers. But its wide extent, its independence of altitude or contours of the ground, its uniform and unstratified character, the unworn condition of its compact particles, and the nature of its organic remains, show that it cannot be assigned to the action of large bodies of water. They, in fact, seem to be due, in the main, to the long-continued drifting and deporting of fine dust by wind over areas more or less covered with

grassy vegetation, aided by the washing influence of rain. This opinion is practically substantiated (*a*) by the fact that where rain is distributed somewhat generally throughout the year little dust is formed; but where dry and wet seasons alternate, as in central Asia and in the southwestern part of the United States, vast quantities of dust may be moved during the months of dry weather (Richthofen). When the dust falls on bare dry ground, it is eventually swept away by the wind, but where it settles down on ground covered with vegetation it is in a great measure protected from further transport, and heightens the soil."[5]

Geikie again says, in substance:[6] The origin of the loess is a problem which has given rise to much discussion. It has been regarded by some writers as the deposits of a vast series of lakes; by others as a sediment washed over the surface of the land by abundant rainfall; by others as deposits left by swollen rivers discharged from the melting ice-fields. The remarkable unstratified character of the loess as a whole, its uniformity in fineness of grain, the general absence of coarse fragments, except along the margins, where they might be expected, its singular independence of the underlying contour of the ground, and the almost total absence in it of fluviatile or lacustrine shells, seem to prove conclusively that it cannot have been laid down by rivers or eskars. On the other hand, its internal composition, the thoroughly oxidized condition of its ferruginous constituents, its distribution, and the striking character of its enclosed organic remains, point to its having been accumulated in the open air, probably in circumstances similar to those which now prevail in the dry steppe regions of the globe. It appears to mark some arid interval after the height of the glacial period had passed away, when, whilst the climate remained cold and the Arctic fauna had not entirely retreated to the north, a series of grassy and dusty steppes swept across the heart of Europe and America.

As to the origin of the loess LeConte, in substance, says:[7] Over large areas bordering the Mississippi and its tributaries, and forming conspicuous bluffs of these rivers, there is found

5. Geikie, Text-book of Geology, p. 332. [This last theory is in accord with the writer's observations in the southwestern part of the United States. The adobe clays on top of the basalt northwest of Fort Apache, Ariz., are being added to year by year by dust accumulation.]

6. Loc. cit., p. 1060.

7. Elements of Geology, p. 583.

a peculiar deposit of very fine, even-grained and usually unstratified material, remarkable for forming by river-erosion perpendicular walls—although soft enough to be easily spaded. It is usually destitute of organic remains, but when these are found they consist of fresh-water shells and especially land shells. When fresh-water shells are found, the material is usually obscurely stratified. Similar bluff-materials are found bordering nearly all European rivers, such as the Rhine and Danube, and is there called loess, and referred to the Champlain epoch.

A somewhat similar material, however, is found also spread over wide areas in many countries, especially in arid regions. These have no obvious connection with any rivers. Such is the case in northern China and also in the Basin and Rocky Mountain regions.

The loess of the Mississippi and its tributaries, as also of the European rivers, was probably deposited in flooded lakes and in the slackened water regions of flooded rivers of the latter Glacial and Champlain epochs. It is poor in fossils, because the waters were ice-cold. It is unstratified, because the waters were overloaded with the very finely triturated material left by the retreating ice-sheet.

The loess of northern China is æolian in formation, according to Richthofen. The unstratified superficial soil of the basin region, Russell thinks, is due partly to wind-borne dust, but mainly to rain-wash. The unstratified soil covering the hilly country at the base of the Alps is attributed by Sacco to rain-wash of the base-soil recently left by the retreating ice.

In writing concerning the loess, Mr. Chamberlin says, in substance:[8] While the larger part of the loess found in the glaciated region of North America is believed to be the product of glacial waters, it still remains, in my view, that certain parts of it were produced by winds. This part in general is believed to have been derived from the water-deposited portion, but perhaps this is not universally true. For instance, the loess collected along the leeward side of the Mississippi river seems to have been derived by wind from the flooded flats of the river below. While coinciding with what seems to be the majority opinion of American geologists, that the loess deposits of the glaciated region are chiefly water-lain, it appears to me prudent, if not important, to recognize the

8. Journal of Geology, vol. 2, p. 537.

æolian class, and to search diligently for criteria of discrimination between the two.

On the same subject Leverett says:[9] "The mode of deposition of the loess still remains one of the most puzzling problems of Pleistocene geology. Both the æolian and aqueous hypotheses have strong adherents. Among the students of the Mississippi valley portion, however, all grant that the influence of wind has been important; and probably all would concede that water had been influential. The division of opinion, therefore, is concerned with the relative importance of wind and water in the distribution of the loess. Mr. Udden, after a careful examination, has decided that a large part of the loess may have been deposited through the influence of the atmosphere as an agent of erosion, transportation, and sedimentation. Mr. Chamberlin says, on this point, that the loess of the Mississippi valley was in some way connected with the great streams of the region. The abrupt border of the loess at the edge of the Iowan drift-sheet, both in Illinois and in Iowa, gives it a more or less direct genetic relationship with the ice. The gradation of the loess into glacial clays further tends to conform the association of the loess with glacial action. The influence of glacial action is also shown in the presence of silicates, which are decomposable under prolonged weathering, and of calcium and magnesian carbonates, none of which can be supposed to be from residuary clays. The loess seems to have been formed by glacio-fluvial action, he (Chamberlin) assuming (*a*) the presence of the ice-sheet at the chief stage of deposition; (*b*) a very low slope of land and consequent wide-wandering glacial rivers; (*c*) the development of extensive flats over which the silts were spread; (*d*) great periodic extension of glacial waters caused (1) by periods of warm weather in the melting season, and (2) by warm rains. Upon the retreat of the waters, he concludes, extensive silt-covered flats would become exposed to the sweeping influence of the wind; and when dried the silt would be borne in great quantities over the adjacent uplands. Thus were formed the æolian loess, the aqueous loess having been formed by the first process above mentioned. Again, he says: "While individual types of both deposits (æolian and aqueous) are not difficult to find, a criteria or series of criteria of gen-

9. G. S. Mon. xxxviii, p. 177.

eral applicability which shall distinguish the two and assign to each its appropriate part are wanting."

Mr. Udden says[10] that "the wind has been very important and perhaps more potent and far-reaching in its influence in the forming of the loess than water deposition," his opinion being based upon his study of the wind as a geological agent. "It is necessary," he continues, "to speak of the objections to aqueous deposition based upon topographic relations of the loess. This deposit not only borders valleys, but blankets interfluvial tracts as well, often resting on an eroded surface like snow. It is found on the highest as well as the lowest parts of previously eroded tracts. It is not rare to find it occurring at elevations differing several hundred feet within the distance of a few miles. The occurrence of terrestrial shells in the loess is also a serious objection to the aqueous deposition theory, especially of deposition in a large body of water.

"Adequacy of wind, as shown in the Mississippi valley, to form æolian deposits, is shown as follows: (*a*) The universal presence of mineral dust in the atmosphere, and its constant settling, necessitates its accumulation in places where erosion is at a standstill or where it does not exceed the rate of atmospheric sedimentation. (*b*) Erosion of the flat, loess-covered uplands is at the present time exceedingly slow as compared with the average rate of denudation of the whole Mississippi valley.

"Rain-water on a level surface appears to soak into the ground as rapidly as it falls, even in the heaviest rains. This is especially true where the surface is covered with vegetation. By far the greater part of the land area in the region of the loess consists of such flat land. And where the drainage of the area is so sluggish as not to equal the secular accumulations of atmospheric dust on the land surface, loess dust would of course accumulate.

"In this mechanical composition fine wind-sediments and loess are largely identical. The bulk of each consists of particles 1-16th to 1-64th of a millimeter in diameter, with two nearly symmetrically decreasing series of admixtures above and below their size. No aqueous deposit with such a range of altitude in so few miles could be so uniform in its mechanical composition as the loess is. Again, were the deposits composed of as fine material as it is and laid down by water, it would

10. Bull. Geol. Soc. Amer., vol. IX, p. 6.

show a bedded, laminated structure. Wind action alone can account for its being such a compact substance as it is.

"The multiple age of the loess is as easily accounted for, as with the many climate changes attendant upon the periods of the ice age, conditions may readily at different times have so far favored the work of the wind as to have allowed the accumulation and the preservation of its sediments."

Concerning the loess deposits of Montana, N. S. Shaler says:[11] "The condition of the formation of this loess deposit may be observed at any time when the earth is dry and the wind is strong enough to lift the dust, as is the case for a considerable part of the year. From the surface of the benches of the valleys, as well as from the scantily vegetated lower parts of the mountain ranges, dust is blown to and fro in large quantities. So long as it encounters no closely set vegetation it does not come to rest. It is only when it finds its way amid densely set plants in the limited areas watered by snow-fed streams that it escapes from the controlling winds. In such places it is quickly fixed, to remain so as long as the natural or artificial irrigation continues. The process of wind erosion here, as elsewhere under like conditions, serves to produce and transport a great amount of fine detritus to the position where it may be readily taken up by the rivers and sent on its way to the sea. The result of this action is at once to increase the efficiency of river work, and to overburden the streams with fine sediment. Incidentally it serves to diminish the down-cutting of the upper parts of a river system, the parts just below the true torrents in which arid conditions most occur, by overloading the waters with transporting material. Thus, in an arid mountainous region there is an upper zone of true torrent work, and below it a valley zone where the erosion is of a very contrasted nature, being evenly and widely distributed with and ærial delivery of the detritus of the streams."

Concerning the loess of Minnesota, F. W. Sanderson, in substance, writes:[12] "The loess as a deposit in this region is never more than a thin veneer, seen occasionally on the highest hills. It is therefore scarcely a typical loess, since being near the surface the humic acids have, from time to time, as it was laid down, had ready access to it. It is a wind-borne dust that was

11. Bull. Geol. Soc. Amer., vol. X, pp. 246, 247.

12. Bull. Geol. Soc. Amer., vol. X, p. 349.

not deposited rapidly enough to produce deep and wide beds of loess. Its blanket-like distribution, its evanescent relations to the soil above, and the undoubted water or ice deposits below strongly suggest that the material springs from the finely subdivided glacial debris scattered during the periods following the ice invasions. Touching the further question of evidence that this loess is æolian instead of aqueous in origin, the following points can only be summarily stated: (*a*) The loess of Minnesota does not occur in any one of the 1000 lakes of that state, existing or extinct, whose deposits have been described. (*b*) It does occur on the higher levels of the glacial drift. (*c*) When in relation with dune sands, it is found higher than they; whereas, as a water deposit it would be lower—that is, farther from the shore-line of deposition. (*d*) It is frequently liable to carry loam within it, thus pointing to zones of vegetation."[13]

Concerning the loess of Iowa, Mr. Shimek says:[14] "It will be observed that the proportion of local aquatic shells found in the loess here and elsewhere[15] is comparatively insignificant, and what is true of species applies with even greater force to individuals. The fossil shells of aquatic species occur very sparingly, and even the aquatic fossils found belong to the fauna of small ponds or streamlets, which may, and often do, remain dry during the greater part of the summer, and their presence in nowise proves that large bodies of water existed where the loess was deposited. Indeed, the total absence of species which are truly fluviatile, or which at least prefer large bodies of water, would point to the contrary conclusion. Had large streams or other bodies of water existed where the loess is deposited, thus furnishing conditions favorable to a fluviatile fauna, it is reasonable to suppose that some of these shells would be found fossil to-day to relate the story of the conditions under which they existed; yet no such evidence has ever been found in undoubted, undisturbed loess, and the conclusion that such large bodies of water did not exist where loess is found is irresistible. Indeed the moluscan fauna of the loess points to comparatively dry upland terrestrial conditions, such as exist over the greater part of Iowa to-day. It

13. In this paper paragraphs within quotation marks are usually quoted direct, though not always. In all cases, however, where the quotation marks are used they are in the main the language of the author quoted.

14. Amer. Geol., vol. XXXVIII, 1901.

15. Given on the Identification of Recent and Fossil Molluscas at Iowa City. See Amer. Geol., vol. XXVIII, pp. 345-357.

suggests land surface clothed with vegetation offering shelter and food to snails—a vegetation developed under medium conditions of moisture and temperature, such as exist here (in Iowa) to-day."

Mr. Leverett again says, concerning the loess:[16] "The northern border of the loess, both in western Illinois and in eastern Iowa, appears to have been determined by the ice-sheet. The loess is apparently an apron of silt spread out to the south by water issuing from the ice-sheet. It is loose-textured at the north and is finer textured toward the south, showing a decrease in the strength of the depositing currents. The wide extent of the loess over uplands has led to a consideration of the influence of wind as well as water in its distribution. The wide extent, however, appears to be due to water distribution rather than wind. Wind action apparently came into force subsequent to the water distribution and is minor in importance."

Concerning the loess in Wisconsin, Mr. Salisbury says:[17] "The loess at Devil's lake and at Ableman's, like that in the vicinity of Green lake, was certainly deposited by water, and water associated with the ice of the last glacial epoch. With the loess at Ableman's is to be correlated the clay in the valley of the Balboa and the loams and clays in various other parts of the state. It is distinctly stratified in places, and constitutes, at any rate covers, the valley flats."

Summary of Opinions Concerning the Origin of the Loess.— The adobe clays of the West and the loess of China are undoubtedly and universally accepted to be of æolian formation. But the deposits throughout the Mississippi valley are said by Chamberlin, Leverett and others to be in the main a silt formation derived from the ground-up rock-flour of the glacial drift deposits. They further believe that the deposit was laid down in the slow-moving water in the rivers and smaller streams at the foot of the glacier. To this hypothesis, however, there are many objections, some of which are: (*a*) The loess continued from Wisconsin along the Mississippi to the delta of that stream. (*b*) The composition of the loess of China and the adobe of the southwestern part of the United States is said to be identical with that of the loess of Iowa, which seems to be good evidence that both were formed in the same way. (*c*) The

16. Jour. of Geol., vol. IV, p. 244.
17. Jour. of Geol., vol. IV, p. 929.

loess deposits of the lower Mississippi valley, the loess of China, the Albuquerque loess (Herrick), and many other loess deposits are not within 500 miles of any glacial region. (*d*) The loess of the Mississippi river and tributaries is on the leeward side of the streams, or is at least highest on that side, which seems to be good evidence of wind accumulation. (*e*) The loess varying in altitude from 500 to 1000 feet within a few miles at many places in the central valley of the United States seems to be an unsurmountable obstacle to the water-deposition theory. (*f*) It is difficult to see how sediment of any sort could be deposited in water without being stratified, the loess with few exceptions being unstratified. (*g*) The fossils in the loess of Iowa as well as in that of the Rio Grande region, New Mexico, are, with two exceptions, all land species, and the exceptions belong to the pond type of fossils, thus seeming to indicate that no large body of water ever occupied the region during the formation of the loess. To use the words of Mr. Shimek, above, "had large streams or other large bodies of water existed where the loess is deposited, thus furnishing conditions favorable to a fluviatile fauna, it is reasonable to suppose that some of these shells would be found fossil to-day to relate the story of the conditions under which they were deposited. Yet no such evidence has ever been found." The fossils of the loess, identified by Shimmek and others, are identical with those now found on the steppes of Asia, where that deposit is now in the process of formation. The evidence from this point of view, that taken by Mr. Shimmek, seems to point to the conclusion that the loess was formed by subaerial action which was principally æolian. The ever-blowing winds blew dust from the mountains, table-lands and plains and from the barren areas at the foot of the glacier. This dust collected in grassy regions and in the valleys and canyons, where it was so protected that it was not moved farther by the winds. There it accumulated, the puzzle of the geological world.

Again, to return to the view taken by Messrs. Chamberlin and Leverett (and they are still finding evidence to verify their hypothesis), the loess seems to have been deposited, for the most part, by glacial streams at or near the foot of the ice-sheet. To use the substance of Mr. McGee's conclusion on this subject, (*a*) the loess is commonly fine, homogeneous, free from pebbles or other adventitious matter, and either massive or so obscurely stratified that the bedding plains are usually

obscure or inconspicuous. (*b*) It commonly contains unoxidized carbonate of lime in such quantities as to effervesce freely under acids. (*c*) It frequently contains nodules and minute ramifying tubules of carbonate of lime. (*d*) In many regions it contains abundant shells of land and fresh-water mollusca. (*e*) It is commonly so friable that it may be removed with a spade or impressed with the fingers; yet it resists weathering and erosion in a remarkable manner, second only to the more obdurate clastic or crystalline rocks.

In the north of Iowa the loess grades either into water-laid gravel-beds or into stratified sand, and in the middle latitudes it commonly passes into stratified and evidently water-laid sand. At the south it grades either into a peculiarly assorted but variable glacial deposit evidently modified by contemporaneous aqueous action, or into water-laid sand. So the stratigraphic relations, apart from the structural features, ally the formation with water-laid deposits and indicate a certain community of origin between its finely comminuted materials and the coarser aqueo-glacial materials of its base. It is the finer grist of the ice-mill laid down in ice-bound lakes and gorges as the Pleistocene glacier shrunk by surface melting and retreated northward.

Remarks on the Origin of the Loess.—It seems evident that a large part of the loess is æolian in formation; but further investigations and the discovery of criteria by which it can be distinguished from the aqueous type are yet needed to determine how much. It is quite probable that the æolian and aqueous agencies worked simultaneously in the same region, and this accounts for the geological tangle. As the glacier departed the plains of America it must have left a barren strip in its rear many miles in width, an area at its final retreat probably half as large as the United States. In this barren waste the agencies of water and wind vied with each other in moving the lighter material left by the ice-sheet. The streams deposited their sediments in the slackened-water regions, while the wind drifted its deposits everywhere, mixing with the aqueous formation wherever it came in contact with it, otherwise depositing it on the leeward side of obstructions and in the grassy regions to the south, which were gradually advancing northward as the glacier retreated.

GLACIAL MARINE DELTAS.

1. Deltas Deposited in Front of the Ice in the Open Sea.—This class spread outward in round or irregular fan shape when deposited over broad and rather level plains where they were free to expand in all directions; but in narrow valleys their slopes were necessarily determined in part by adjacent hills. They conspicuously show the characteristic horizontal transition of sediments, from coarse at the north to finer material toward the south, that is, away from the mouth of the glacial river. The delta indications are unmistakable.

2. Ice-bordered or Narrow Marine Deltas.—These are usually much longer from north to south than from east to west, having but little of the fan shape. At their southern ends they pass by degrees into clays having the same level, like the delta plains above described. They are found in valleys or level regions much broader than they are, where there is no topographical reason why a delta, if deposited in the open sea, should not have spread outward in fan shape. Evidently the glacial rivers flowed into channels which were open toward the sea, but at the sides were bordered by ice which covered the rest of the valleys and prevented the delta from spreading out.

That these deltas are marine is attested by the marine fossils.

Fringing Lake Sediments.—This class embraces deposits of suspended material brought out from the ice into the bordering lakes by glacial streams and spread over their bottoms. It is a somewhat stratified material of the clayey type, sometimes bearing lacustrine fossils. It is often commingled with stony material dropped by floating ice from the edge of the glacier, but not in noticeable quantities. It is also always commingled with wash from the adjacent land not covered by ice.

Bordering Sea Sediment.—This class differs from the preceding in the fact that the waters were not impounded in ice, and in the fact that the deposits are commingled with oceanic sediments and marine fossils, and impregnated with saline waters, which may or may not have been wholly removed subsequently.

Local Formations Produced by Floating Ice.—These de-

posits were laid down by fringing glaciers in lakes (lakes usually formed by glacial damming) or in the ocean.

FOREIGN FORMATIONS PRODUCED BY FLOATING ICE.—These are essentially marine deposits, and are due to icebergs derived from distant glaciers. These bear to the point of deposit material wholly of foreign origin.

SHORE RIDGES DUE TO ICE PUSH.—In the northern latitudes the shore action of ice (not including icebergs) is very noticeable, producing shore ridges of unusual strength.

LITTORAL DEPOSITS.—If we confine the above class to those ridges which were pushed upon shore above the reach of the waters, we need also to recognize a class which was deposited beneath the border of the body of the water, since they were deposited by ice action. To this class is given the name "littoral deposits."

OFF-SHORE DEPOSITS.—These embrace the material of the ice action off shore borne back in suspension or by ice-flows into still waters and there deposited. They must, in the nature of the case, simulate the formations produced by floating ice derived from glaciers (Chamberlin).

DUNES.—These are dunes similar to any other class of dunes, except that the material is made up, in part, of grains formed by glacial grinding instead of disintegrated and wave wear, and in their correlation with the ice-border and the glacial waters that issued from the ice, rather than with the sandy shores of lakes and rivers (Chamberlin).